

50 nm thick AlN Films for Actuation and Detection of Nanoscale Resonators

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We report on the optimization of a multilayer platinum/aluminum nitride (AlN) stack with an AlN active layer thickness of 50 nm for piezoelectric actuation in nanoelectromechanical systems (NEMS). Experiments in reactive sputtering of AlN were used to find optimal parameters for good crystallinity and low residual stress of a four layer film stack, shown in Figure 1. A direct relationship was measured between the AlN seed layer thickness and the x-ray diffraction (XRD) rocking curve's full width at half maximum (FWHM) of the AlN active layer. However, no influence of seed layer thickness was found in double beam laser interferometric measurements of the clamped longitudinal piezoelectric coefficient $d_{33,f}$, relating thickness strain from an applied electric field, of the XRD measured four layer film stacks.

Piezoelectric actuation is particularly attractive for its high efficiency, integratability, low power consumption and scalability to the nanoscale. AlN thin films offer a high PZE coupling as well as good mechanical, chemical and thermal stability. Reactive sputtering was chosen as the means of deposition to have the ability to deposit at low temperatures on metalized substrates.

It has been reported [1] that the sputtering conditions and underlying film have strong influences on the quality of deposited AlN thin film. Sputtered AlN films with thicknesses below 100 nm have large residual compressive stresses as well as low $d_{33,f}$ relative to micron thick films [2,3]. It has also been reported [4] that stress can significantly influence the stiffness of nanocantilever beams; thus it is imperative to optimize sputtering conditions to use AlN thin films in NEMS resonators. As reported by Martin et al. [2], there is a direct relationship between the piezoelectric coefficient $d_{33,f}$ and the FWHM of XRD rocking curves of the AlN (0002) crystallographic peak. FWHM can therefore be used as a non-invasive figure of merit in determining good sputtering conditions, along with residual stress measurements.

To optimize the four layer film stack's overall piezoelectric and material properties, a series of depositions were completed on a Pfeiffer SPIDER 600, a reactive, DC pulsed magnetron sputtering system. All four layers were deposited consecutively during each experiment. During active layer depositions, the chamber temperature and power applied to the target were varied between 200-350°C and 1000-1500 W, respectively. The measured FWHM and residual stress for each deposition setting is shown in Figure 2. The best compromise of low compressive stress and small FWHM is obtained with an applied target power of 1500 W and a deposition temperature of 300°C. Physically, having both a high applied target power and high temperature increases the energy of the impinging atoms and their adatom mobility on the growing film surface. However, this potentially stores more energy in the film by the peening effect of ion bombardment, thereby increasing the compressive stress in the film [1].

The influence of the AlN seed layer thickness on the four layer film stack with otherwise similar depositions conditions and film thicknesses was measured with XRD and double beam laser interferometry. Figure 3 compares the FWHM of 4 different seed layer thicknesses versus the full stacks with the same seed layer thicknesses. Counter-intuitively, increasing the seed layer thickness from 15 to 100 nm increases the FWHM of the full stack by 1°. However, as can be seen in Figure 4, the measured $d_{33,f}$ on the four layer film stack for 5 different fabricated electrode radii showed no significant difference between the different seed layer thicknesses. A possible reason for these opposing results is that as the seed layer grows thicker, it contributes more to the (0002) peak, which then broadens due to the seed layer and active layer peaks combining into one peak. This skews the XRD results while not influencing the $d_{33,f}$ results.

Future work will be focused on minimization of the compressive stress of the four layer film stack to fabricate NEMS resonators for high frequency applications.

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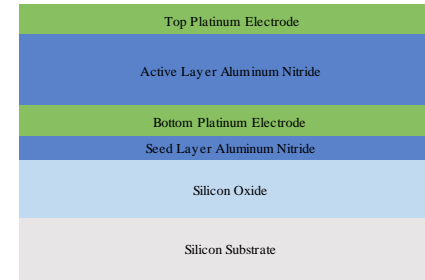


Figure 1. Diagram of four layer film stack consecutively sputter deposited on 100 mm oxidized silicon wafers: seed AlN layer (variable thickness), bottom platinum electrode (25 nm), active AlN layer (50 nm) and top platinum electrode (50 nm). Not to scale.

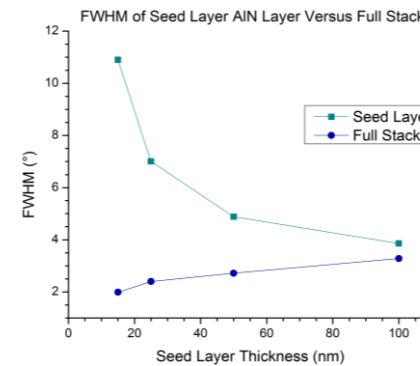


Figure 3. Comparison of FWHM of standalone seed layer AlN versus the full film stack for 15, 25, 50 and 100 nm seed layer thicknesses. Circular electrodes of 190-500 μm radii were fabricated on the full stacks. As the seed layer increases in thickness, the seed layer's FWHM decreases while the film stack's increases.

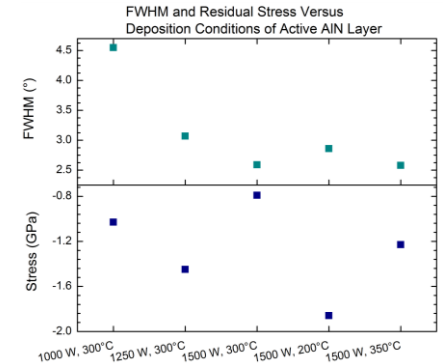


Figure 2. Results of different applied target powers and temperatures on the rocking curve FWHM of the (0002) AlN peak (top) and residual stress of the film stack (bottom). Optimal stress/FWHM conditions are for 1500 W and 300°C.

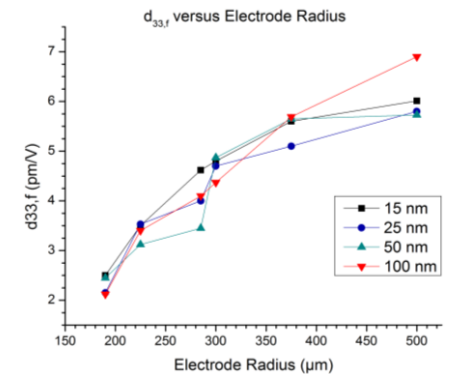


Figure 4. Measured $d_{33,f}$ on full stacks with 15, 25, 50 and 100 nm seed layer thicknesses. Circular electrodes of 190-500 μm radii were fabricated on the full stacks. No significant difference is seen between different seed layer thicknesses.